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ENGINEERING TECHNICAL NOTE

Subject *IRRIGATION*

No. *210-19-TX2*

Reference : *ADAPTATIONS AND LIMITATIONS OF SELF
PROPELLED CENTER-PIVOT SPRINKLER IRRIGATION
SYSTEM*

Date : *AUGUST 1982*



**SOIL CONSERVATION SERVICE
U.S. DEPARTMENT OF AGRICULTURE**

No.: 210-19-TX2

IRRIGATION

ADAPTATIONS AND LIMITATIONS OF SELF-PROPELLED
CENTER-PIVOT SPRINKLER IRRIGATION SYSTEMS

This technical note contains general information and guidelines for use by Service personnel to:

- 1 Assist cooperators who are planning to purchase sprinkler irrigation equipment.
2. Help improve the operating efficiency of existing center-pivot systems.
3. Recognize the limitations of this type system when planning sprinkler irrigation or determining the need and feasibility of installing underground pipelines under cost-sharing programs to deliver water to center-pivot systems.

In recent years the self-propelled center-pivot sprinkler irrigation system has become increasingly prevalent. Several hundred of these systems are in use in Texas. Although the largest concentration of center-pivot systems is in the High Plains land resource area, they are used in varied numbers in most of the State's irrigated areas. The scarcity of farm labor to move sprinkler pipe and to manipulate surface irrigation systems has brought about the demand for automatic irrigation systems. This seemingly is the major factor contributing to the increasing number of center-pivot systems.

More than fifteen different companies manufacture self-propelled center-pivot sprinkler irrigation systems. Although the various makes may differ in appearance, certain mechanical features, and kind of power used for a self-propelling, the basic principles of design and operation are very similar. This type system consists of a single line of sprinklers supported above ground by A-frame type towers having wheels, tracks or skid shoes powered by electricity, air, or oil or water hydraulics to rotate the sprinkler line around a center pivot point. Irrigation water enters the system at the pivot point. Uniformity of application along the line is achieved by increasing the application rate in proportion to the distance from the pivot and the segment of the circle irrigated. Moving outward from the pivot the required change in application rate is accomplished by increasing the discharge capacities of the sprinklers or decreasing the spacing of sprinklers having the same capacity. The key characteristic which affects the adaptability of these self-propelled systems is the variable application rate.

Adaptations

Some of the main advantages of center-pivot systems and conditions under which they are best suited are:

1. According to manufacturers' literature, center-pivot systems are available in sizes from 10 to 330 acres. But, most manufacturers' basic unit is designed to irrigate 120 to 140 acres out of a quarter section. By reducing the length of line and corresponding area of coverage, this type system can be adapted to fit small irrigation water supplies. The SCS in Texas considers 3 gpm/ac as the minimum water supply for such systems.
2. The center-pivot system is automatic. It is designed to rotate continuously about its pivot and to cut itself off if a segment of the line gets too far out of alignment. Propulsion of some systems can be reversed. This affords distinct operational flexibility in that parts of a circle may be irrigated repeatedly without making a complete revolution. Rotation time varies by make and type of system. As will be seen later, this is an important consideration when selecting a system for specific soil conditions.
3. These systems have the ability to operate on relatively rough terrain. Some manufacturers state that their systems will successfully negotiate grades of 20 percent and greater. However, experience indicates that systems operated on flatter and smoother topography have less mechanical failures and cutoffs due to mal-alignment. As with other types of irrigation systems, the potential for excess runoff increases with land slope. Therefore, this type system should be limited to slopes of less than 5 percent where possible.

The center-pivot systems are capable of traveling over such conservation practices as terraces, diversions and waterways. The type and size of wheels used to support and propel the systems determine in large measure the degree of damage to such practices. Narrow tread tires and wheels cut ruts during irrigation applications, and unless a special effort is made to control the depth of the ruts, terrace and diversion ridges will become ineffective and water concentration routes will develop in waterways and on the steeper slopes. Filling the ruts following a few irrigations (number of times depends on soil characteristics) helps to develop compacted tracks and reduce depth of ruts. The selection and use of a center-pivot system should not forsake the use and maintenance of terraces which are needed for erosion control. Benefits derived from the terraces will more than offset their interference with the operation of the sprinkler system and the terrace maintenance problems caused by ruts.

4. Irrigation water is delivered best to the pivots of these systems by underground pipelines. Special provisions must be installed for the wheels or tracks to cross portable irrigation pipe.
5. The center-pivot system can be moved to different pivot points. However, operating the system at one location for at least a complete irrigation season seems to be the most desirable procedure.
6. When equipped with proper size sprinkler nozzles and operated at recommended pressures, the center-pivot system is capable of relatively high uniformity of application. However, the uniformity of applied moisture in the soil profile is governed, among other factors, by the soil intake characteristics, application rates and depths, land slopes, and soil surface conditions. Since the application rates along the line increase in direct proportion to the distance from the pivot, the rates become significantly higher near the outer part of the circle and may produce excessive runoff on some soils.

Therefore, the center-pivot system is best adapted to sandy soils with relatively high intake rates. On such soils, the rotation time of the system can be adjusted at each irrigation to apply, without excessive runoff, the amount of water required to replace the moisture within the root zone of the crop. Soils grouped in Intake Families 1.0 and above in the applicable irrigation guide are considered suitable for irrigation with center-pivot self-propelled systems under a wide range of cropping systems and average level of management. To obtain acceptable irrigation efficiencies even on the most suitable soils, these systems must be operated as designed to function. This makes it necessary for the operator to have a copy of the system design in order to see that the required sizes of sprinkler nozzles are properly located on the line and that the design pressures are maintained during operation.

Limitations

The versatility of center-pivot self-propelled systems is reduced significantly when these systems are used on soils having low intake rates. Excessive runoff can occur unless the systems are operated so that their application characteristics best fit the intake characteristics of the soil. A high level of management is required to do this because the operator must understand the characteristics of his soil and be willing to use application techniques which best offset the limitations of the center-pivot system. Some of these characteristics and techniques are discussed below.

As stated previously, the application rate along the line of the center-pivot system varies with the distance from the pivot and becomes greatest near the end of the line. Conversely, the application time on a point near the pivot is longer than on a point in outer part of the circle. Therefore, the application rate increases and the application time

decreases on a point as it moves radially outward from the pivot. Also, the water application rate at a point on the soil surface varies continuously during the time the sprinkler pattern passes over the point and the diameter of the sprinkler pattern influences the time of application on the point. The application depths may be varied by changing the rotation speed of the system or by changing the sprinkler discharges, or both. An understanding of these application characteristics and the intake rates of the soil will enable the operator of a center-pivot system to adjust water application time and depth so that potential runoff will be at a minimum for the system.

Researchers on sprinkler performance define potential runoff as the portion of the water that is applied at rates exceeding the intake rates of the soil. Potential runoff can be substantial on low intake soils with center-pivot systems. Both the amount and distribution of this runoff along the sprinkler line depend on the intake characteristics of the soil. Potential runoff is influenced by the application depth which is controlled primarily by the rotation speed of the system.

Intake rate of a soil varies with time and it is generally accepted that the intake rate at any time depends on the volume infiltrated up to that time. Figure 1-1 illustrates this.

Plotted on Figure 1-1 are sprinkler intake rate curves and the corresponding accumulated intake curves for soils grouped in 0.3 and 0.5 Intake Families and for Pullman cl and similar soils. Water applied in excess of the rates and depths given by these curves would be considered as potential runoff. Figure 1-1 was developed from field test data. Although the intake curves in Figure 1-1 are based on a limited number of field tests, they are suitable for use until they can be refined on basis of research or additional field tests.

Example 1-1 illustrates how the design characteristics of a particular center-pivot self-propelled sprinkler system can be evaluated in relation to the soil intake data from Figure 1-1 to predict potential runoff on soils in 0.3 and 0.5 Intake Families and Pullman cl and similar soils.

It is readily evident from Example 1-1 and other evaluations that the depths of application on these slower intake soils must be limited in order to reduce the potential for critical runoff. Frequent light applications are required in order to take advantage of the higher initial intake rates of these soils. Thus, the amount of water required to replace the moisture within the root zone of the crop cannot be applied at each irrigation with the center-pivot system without exceeding intake capacities of the above group of soils. This is the major limitation of this type system.

Light applications, applied to keep within the intake capacities of the soil, may not fully meet the peak period consumptive use requirements of the crop grown in the circle. This, plus higher rates of water use due to light applications, can cause the crop to go into moisture stress during peak use periods. On the other hand, increasing depths of

applications on these soils to fully meet the crop needs at each irrigation increases the amount of potential runoff. In turn, runoff can decrease greatly the uniformity of moisture applied to the soil within the circle and increase erosion and water loss. Although potential runoff is usually greatest in the outer portion of the circle, it can be substantial near the pivot.

Equations and procedures have been developed for solving the theoretical application rates and depths applied by center-pivot sprinkler systems and for determining amount of potential runoff in relation to soil intake. These procedures are very complex and time consuming without the use of a computer. For this reason, they are not presented in this memorandum but may be found in the references listed. However, a rough estimate of the potential runoff may be made as illustrated in Example 1-1.

Research has shown that for a given amount of potential runoff, actual runoff from a particular area depends on the slope, surface conditions affecting runoff, and position of the area with respect to other runoff-producing areas. These factors are highly variable and cannot be specifically defined with numerical limits. However, things can be done to counteract these factors which contribute to actual runoff even on soils with low intake rates. They are:

1. If the irrigated area is to be double cropped, locate cultivated crops on the flattest slopes and use perennial, close grown, or high residue producing crops on the steeper slopes. Where there is a definite difference in intake capacities, use cultivated crops on the most permeable soil.
2. Make full use of crop residues on surface of soil to retard runoff, and time irrigations to follow cultivations when practical so that soil surface is in rough condition.
3. Adjust depths of applications so that there is an acceptable balance between meeting the consumptive use needs of the crops and permitting runoff. A practical and feasible approach is to tolerate some runoff rather than allow crops to suffer serious moisture stress.
4. Weigh the effectiveness of the big gun sprinkler at end of line against runoff. Potential runoff is usually greatest under these guns. Discontinuing the use of this sprinkler could reduce runoff and significantly improve overall efficiency of a system.

Acceptability

Center-Pivot self-propelled sprinkler irrigation systems are usually capable of applying water at an acceptable level of efficiency to meet crop needs and the characteristics of the soils grouped in Intake Families 1.0 and above. These systems have limitations when used on soils in Intake Families less than 1.0. However, the center-pivot systems can be operated in an acceptable manner on these soils by carefully managing the water applications so that design characteristics

of the systems best fit the intake capacity of the soil. Therefore, this type system is acceptable for use under Standard and Specifications for Irrigation System, Sprinkler provided:

1. Available water supply at pivot is 3 gpm per acre or greater.
2. When for use on soils in the lower intake groups, the landowner recognizes the system limitations discussed above and agrees to manage the system to prevent critical runoff, erosion, and damage to conservation measures such as terraces, diversions, and waterways.
3. Planning statements for irrigation systems and operational plans for irrigation water management clearly recognize and reflect the limitations of the system in respect to the on-site soil properties, cropping systems, and climate. Reference is made to 210-TX523 of the NEM which contains certain instructions on documenting irrigation water management plans.
4. To document a determination of need and feasibility for an ASCS cost-share in connection with underground pipelines, or other qualified distribution facilities, intended to serve center-pivot systems which operate on soils in Intake Families less than 1.0, a statement of the following content and scope should be recorded on the referral form:

First, clearly record the determination. For example: The pipeline is needed and practical, and is feasible to install. The pipeline practice will function as an irrigation water delivery to a center-pivot sprinkler irrigation system.

Secondly, briefly record the site conditions and the apparent limitations. For example: The soils at the irrigation site have basic water intake rates that are relatively low rates. The sprinkler system associated with this pipeline will apply efficient irrigations without runoff for application depths at or less than 1 to 1.5 inches. Larger applications, as may at times be desirable for certain crops in this climatological province, will have the potential to produce irrigation runoff.

Thirdly, record any related information that commonly would be recorded irrespective of the system. For example: To our knowledge this land has been irrigated for the last five years.

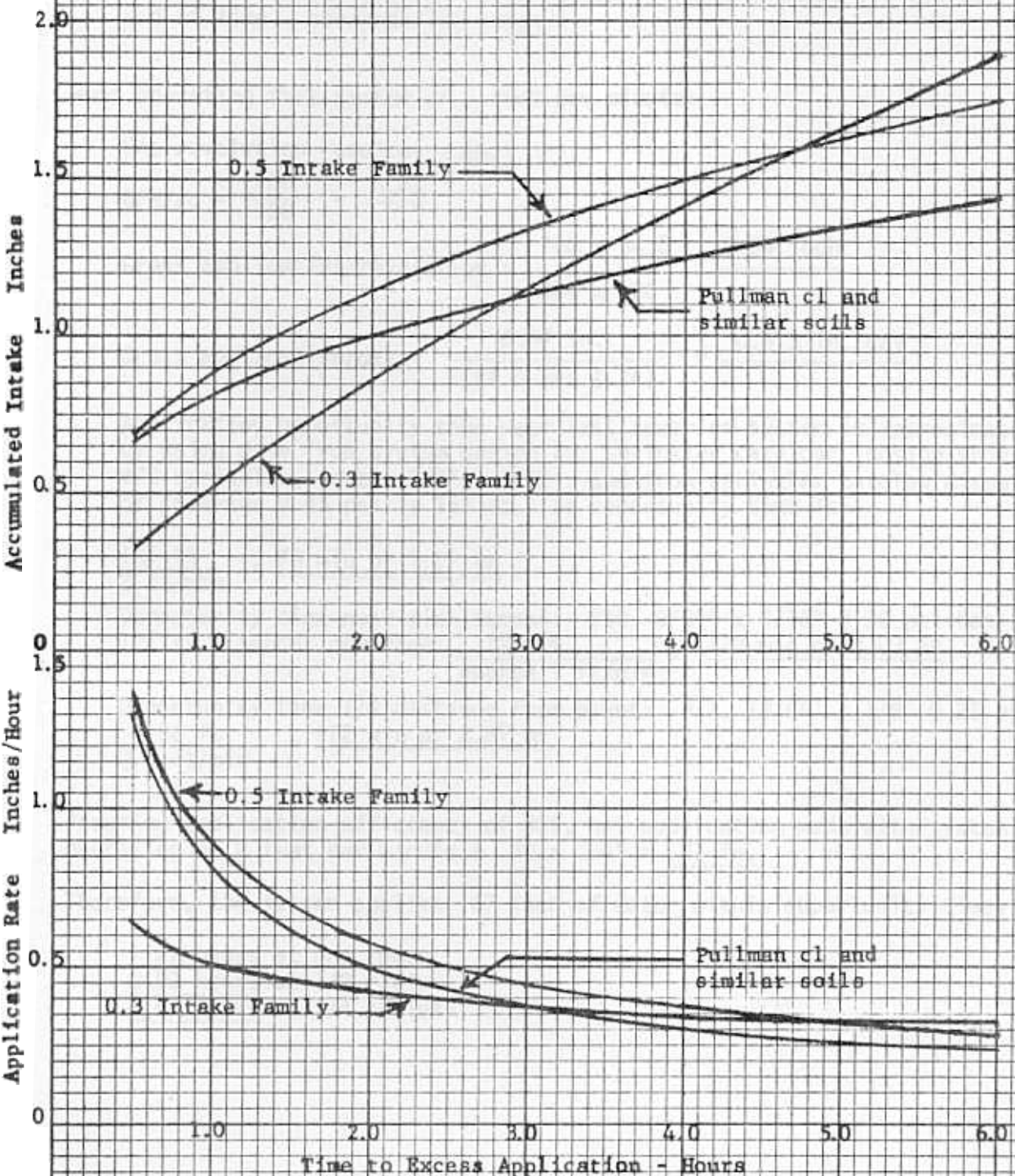
The classical concept for sprinkler irrigation accepts the idea that application rate and set time (opportunity time) can be dimensioned to satisfy all soil properties and irrigation demands without runoff or excessive surface ponding. The operation of a mobile center-pivot sprinkler requires some relinquishing of this concept when the water intake rate of the soil is low or moderately low. When assisting prospective buyers of sprinkler irrigation equipment, SCS personnel should

present the advantages, disadvantages, adaptations and limitations of each type of system. Purchasers of center-pivot systems should be encouraged to have the equipment designed to best fit their water supplies to the intake capacities of the soil. They should obtain and use the system designs in management of water application.

Special emphasis needs to be placed on improving efficiencies of existing self-propelled pivotal systems. Principles and procedures discussed in this technical note will be useful in working with irrigators on this phase.

As time will permit, SCS engineers should gather additional sprinkler intake data as a means of refining the data in Figure 1-1.

FIGURE 1-1
Sprinkler Intake Data



EXAMPLE 1-1

Evaluation of Center-Pivot Sprinkler System
Design in Relation to Soil Intake Characteristics

Given:

1. Pullman c1 soil
2. Well discharge 700 gpm
3. Pivotal sprinkler system - 1285' to be operated without big gun at end of line - coverage 120 acres

When operating this system at 2 feet per minute:

One revolution requires - 64.5 hrs.

$$\text{GPM/ac} = \frac{700}{120} = \underline{5.83}$$

$$\text{Gross application/revolution} = \frac{700 \times 64.5}{450 \times 120} = 0.84 \text{ inch}$$

$$\text{Gross application/day} = \frac{0.84 \text{ in.}}{(64.5 \text{ hrs} \div 24)} = \underline{0.313 \text{ in./day}}$$

Application opportunity time near last tower on system is approximated by using data from system design and sprinkler catalog: design shows #70 sprinkler, nozzle 3/8" x 7/32", and from sprinkler catalog diameter of coverage @ 45 psi is 151 ft. So opportunity time is:

$$\frac{151 \text{ ft}}{2 \text{ ft/min}} = \underline{76 \text{ min or } 1.27 \text{ hr}}$$

$$\text{Opportunity time near mid-lateral: \#30, } 9/32" \times 3/16" \text{ @ 30 psi has } 122 \text{ ft diameter coverage: } \frac{122 \text{ ft}}{\text{approx } 1 \text{ ft/min}} = \underline{122 \text{ min or } 2.03 \text{ hr}}$$

$$\text{Opportunity time } 1/4 \text{ distance from pivot: \#17, } 13/64' \times 1/8' \text{ @ 25 psi - } \frac{86 \text{ ft}}{0.5 \text{ ft/min}} = \underline{172 \text{ min or } 2.87 \text{ hr}}$$

Assuming application efficiency of 80%, net application made with system operating at 2 feet per minute = $.80 \times .84" = \underline{.67 \text{ in.}}$

Therefore, the system applies .67 inch of water within opportunity times of -

1.27 hours at end tower
2.03 hours at 1/2 radius
2.87 hours at 1/4 radius

EXAMPLE 1-1 (Continued)

Intake data from Figure 1-1 for the Pullman c1 soil indicate that the accumulated intake could be equal to or less than the following amounts for the above opportunity times without potential surface runoff -

1.27 hours - 0.88 inch accumulated intake
 2.03 hours - 1.01 inches accumulated intake
 2.87 hours - 1.12 inches accumulated intake

Therefore, this system applies water within intake characteristics of the soil when operated at 2 feet per minute.

Assume that the system is operated at 1 foot per minute in order to apply larger application per revolution and all other conditions remain the same

$$\text{Gross application/revolution} = \frac{700 \times 129}{450 \times 120} = \underline{1.68 \text{ inches}}$$

$$\text{Net application/revolution} = .80 \times 1.68 = \underline{1.34 \text{ inches}}$$

<u>Opportunity time</u>	<u>Maximum accumulated intake for these times</u>
at end - 2.54 hr	1.07 inches
1/2 radius - 4.06 hr	1.25 inches
1/4 radius - 5.74 hr	1.39 inches

At system speed of 1 foot per minute, application rates begin to exceed the intake characteristics of the soil and runoff can be expected to occur beyond 1/4 radius of coverage.

Changing system speed to 1.5 feet per minute and application/revolution to 1.12" gross or .89" net gives -

<u>Opportunity time</u>	<u>Corresponding maximum accumulated intake</u>
at end - 1.69 hr	0.95 inch
1/2 radius - 2.71 hr	1.10 inches
1/4 radius - 3.83 hr	1.22 inches

This evaluation indicates that 1.5 feet per minute is the slowest speed that this system can be operated under stated conditions (700 gpm, 1285' without big gun, 120 acre coverage) without exceeding intake characteristics of the Pullman soil. Also, the maximum well discharge which can be applied on this soil with the 1285' system without potential runoff is approximately 900 gpm with system moving at its maximum travel speed of 2 feet per minute. This is because the additional 200 gpm increases the net application per revolution to 0.86 inch which is about the maximum intake for the soil during opportunity time at outer part of circle.

EXAMPLE 1-1 (Continued)

Potential for runoff along the line can be estimated by dividing the amount of net application that was applied in excess of the accumulated intake for the opportunity time by the net application. For the 1 foot per minute operation speed in the above example, the potential for runoff near the end would be $\frac{1.34 - 1.07}{1.34} \times 100 = 20\%$.

References

- Heermann, D. F., and Hein, P. R. 1968. Performance characteristics of the self-propelled center-pivot sprinkler irrigation system. Transactions of the ASAE II: (I) 11-15.
- Kincaid, D. C., Heermann, D. F., and Kruse, E. G. 1969. Application rates and runoff in center-pivot sprinkler irrigation. Transactions of the ASAE, Vol. 12, No. 6.